Field Testing of Various Energy Saving Measures for Domestic Hot Water Heating in Multifamily Buildings

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Three research projects investigated several strategies aimed at reducing domestic hot water heating (DHW) consumption in apartment buildings. First, the strategy of lowering DHW temperatures during periods of reduced demand was examined for two controls in three buildings with recirculation loops. Second, replacement of an existing DHW heater with a high efficient condensing unit was tested in two cases. Finally, the benefits of using an integral flue damper (IFD) versus a thermal vent damper on commercial tank-type water heaters was studied in two buildings. All tests were conducted using an alternating mode design monitored by a computerized data acquisition system.

Reducing DHW temperatures during low demand proved worthwhile using either a time- or demand-based control. Energy savings averaged 10% of DHW use for the time control and 16% for the demand, with simple paybacks of about 2 years. The seasonal efficiency of the DHW heaters with the test controls was about 38% compared to 35% without. The demand control was easier to operate and appears less likely to cause complaints or be overridden. Savings for the high efficiency DHW heaters were about 28%, with paybacks of 24 and 28 years respectively. Calculated paybacks based on the incremental cost of a high efficiency heater over a conventional heater were still 20 years. DHW heater seasonal efficiencies were 54% and 58% for the existing equipment, and 77% and 81% for the condensing units. The damper study indicates no significant reduction in DHW energy use from thermal dampers. Integral dampers saved 6% and 4% of DHW use, with paybacks of 43 and 32 years. Comparative paybacks based on the incremental cost of an IFD heater were 9 and 12 years. DHW heater seasonal efficiencies were 64% and 62% with no damper, compared to 68% and 65% with the integral damper.

Introduction

Domestic hot water (DHW) heating accounts for 15% to 27% of the total energy use in Minneapolis apartment buildings, not counting the energy used for lighting and electric appliances (Dunsworth et al. 1988). To date, very little research has focused on retrofits aimed at reducing DHW energy use. This lack of reliable data makes it difficult for multifamily building owners to select appropriate options for DHW heater upgrades or replacements. As a result, owners tend to make selections based on lowest first cost, which often means lower efficiency. To rectify this, the Center for Energy and the Urban Environment and the Energy Resource Center investigated several promising strategies aimed at reducing DHW use in apartment buildings. The purpose was to assess the energy use, performance and tenant acceptability associated with these measures.

The first measure examined was that of lowering DHW temperatures during periods of reduced demand, a strategy which is primarily intended for DHW systems with recirculation loops. This retrofit was examined for two controls in three buildings. The other two measures investigated focussed on replacement equipment, since this is perhaps the best opportunity for efficiency upgrades. One equipment option, examined in two buildings, was the replacement of an conventional tank-type DHW heater with a high efficiency condensing unit with a recovery efficiency of 94%. The other replacement option, also studied in two buildings, explored the efficiency benefit of installing a commercial tank-type DHW heater with an integral flue damper versus a standard vent damper.

Description of Retrofit Strategies, Test Sites and Test Design

Recirculation Loop Controls

A major factor in DHW energy use in apartment buildings is the presence of a return piping system, common in buildings of 40 units or more with central DHW heaters.

In this system, hot water is circulated through a supply loop so that it is readily available at taps. Usually uninsulated, this supply loop can be a large source of heat loss (Sachi et al. 1989; DeCicco 1988; Perlman and Milligan 1988; Robinson et al. 1986). Certain retrofit strategies for reducing loop loss (eg; insulating the piping loop, permanent DHW temperature reductions, turning off the recirculation pump) tend to be impractical because of accessibility problems or tenant objections. An alternative is to reduce loop temperature during light demand, which reduces loop losses while keeping hot water continuously available. Savings are expected from several sources. First, direct heat losses from the circulation loop will decrease. Second, the energy required to satisfy fixed volume uses (i.e; clothes and dish washers) will be less. Finally, the seasonal efficiency of the DHW heater (i.e; the ratio of useful heat delivered during the entire year, over the heat available in the fuel) will improve because of reduced off-cycle jacket and flue losses. If savings from the later two sources are high enough, this strategy may also be applicable to DHW heating systems without return loops.

Three sites were selected for the study, all constructed after 1960 and with central gas-fired, zoned hydronic heat (1, 2 and 3 in Table 1). Two of the sites have 39 units and 78 tenants, while the third has 47 units and 75 residents. All three buildings have on-site laundries and two have dishwashers. Each site has two conventional, commercial, gas-fired, tank-type water heaters plumbed in parallel with connected recirculating loops. All DHW heaters have standing pilots and no vent dampers with rated inputs of roughly 200,000 Btu/h to 250,000 Btu/h each.

Existing DHW controls were fixed-temperature aquastats supplied by the original equipment manufacturer (OEM) and were left in place. The three buildings were retrofitted with two types of controls that provide automatic temperature adjustment. One of these controls was an electronic time-based control with fixed set-up and setback temperatures and times, and a seven-day program with up to six events per day. The other control was an electronic demand-based control which monitors firing time on the DHW heater (interpreting increased firing as higher demand and decreased firing as less) and adjusts system temperatures up or down accordingly. For this control, the rate at which temperature increases, the rate at which temperature decreases, and the time before the temperature change is initiated can all be varied.

Regulation of the DHW systems in each building was rotated among the three control strategies for consecutive one-week periods throughout the year long study. During the fixed-setpoint mode, the aquastats in each building were set at the temperature at which they were initially found (nominally 140°F, 134°F, and 140°F for sites 1, 2 and 3), and the systems were allowed to operate as before the retrofit. At periods when the DHW system was regulated by the time control, temperatures on the system were switched between a high setpoint (pre-retrofit temperature) and a low setpoint (115°F), depending on a preset program. The setback program (our best estimate of tenant demand) was the same for all sites and initially included setbacks both at night and during the day. When operated by the demand control, the temperature of the DHW system was maintained between a user-selected minimum (115°F) and maximum (145°F), but the temperature at any given point depended on actual demand.

Table 1. Description of Test Sites And Domestic Hot Water Systems

	Recirculation Controls			High Eff Heater		Integral Damper	
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Year Built:	1970's	1970's	1960's	1911	1913	1915	1927
# Stories:	4	4	8	3.75	3	3	3
# Units:	39	39	47	6	9	14	20
# Occupants:	75	78	78	12	12	16	24
# Dishwasher:	12	0	47	0	0	0	0
# Wash Mach:	3	3	3	1	1	2	2
DHW Htr Type:	Tank	Tank	Tank	Tank	Tank	Tank	Tank
# of DHW Htrs:	2	2	2	1	1	1	1
Htr 1 Capacity Gal:	100	100	84	50	75	92	100
Htr 2 Capacity Gal:	100	84	76	n/a	n/a	n/a	n/a

High Efficiency Hot Water Heater Replacement

While significant work has been done to develop and market high efficiency heating and DHW appliances suited to single family homes, very little has been targeted to multifamily buildings. Efficiency testing and rating of DHW heaters by the Gas Appliance Manufacturers Association (GAMA) does not typically include equipment appropriate for apartment buildings since it is restricted to gas tank-type heaters with inputs of 75,000 Btu per hour or less. Other than using a high efficiency residential heating boiler with a storage tank, there are limited high efficiency options available for heating DHW in larger buildings. Furthermore, operating costs among alternatives cannot be compared easily due to the lack of standardized ratings.

In order to assess the performance of the "best available technology" for this application, a field test was completed using a very high efficient, condensing water heater with a recovery efficiency of 94%. (While this unit is too large to be rated by GAMA, the manufacturer estimates an energy factor of about .86.) The heater is forced draft, has a capacity of 34 gallons, a rated input of 100,000 Btu per hour, and a recovery rate of 124.5 gallons per hour (at 90°F temperature rise). Given the small capacity on the test DHW heater, two buildings under 10 units each were selected as test sites (4 and 5 in Table 1). Both buildings are older (circa 1910) and have forced hot water heat with a single heating zone. Neither building has dishwashers but both have on-site laundry facilities, a very typical arrangement for older buildings. Each site had an existing gas-fired, tank-type DHW heater controlled by a constant temperature OEM aquastat. Rated heater inputs were 40,000 Btu per hour for site 4 and 76,000 Btu per hour for site 5.

At each site, the high efficiency heater was installed in parallel with the existing system, and plumbed to supply hot water to the building independent of the original system. At site 5, a 50 gallon secondary storage tank was also installed to provide additional capacity to meet anticipated demand. In this later system, hot water was supplied to the buildings directly from the secondary tank, whereas incoming cold water was directed to the high efficiency heater. If temperatures in the secondary tank dropped below a setpoint, water was circulated to the high efficiency heater until the setpoint temperature was satisfied. Throughout the nine month test period, operation of the existing and high efficiency heaters were alternated for one week periods. The temperature of hot water supplied to each building by each system was adjusted to assure that roughly the same average temperature was provided for both test modes.

Integral Flue Damper Versus Thermal Vent Damper

Research by Ontario Hydro suggests that standby losses (including stack and jacket losses) can account for as much as 13% of the total energy used to heat DHW in apartment buildings (Perlman and Milligan 1988). One of the few high efficiency upgrades available on standard commercial tank-type hot water heaters at the time of purchase is an electric integral flue damper (IFD). IFD's are factory-installed upstream of the draft diverter, reducing stack related standby losses. In contrast a retrofit vent damper (whether electric or thermal) is installed downstream of the draft diverter. This arrangement allows heated air from the DHW flue passage to be continually spilled into the boiler room where it is unlikely to be useful and may simply escape to the outside through any undampered flue. The cost differential for an IFD package is only about $500 to $600, but without credible performance data, our experience indicates that owners are unwilling to risk even such a minor cost differential. Previous research at one site showed savings of roughly 6% to 10% (Nevitt and Stefanson 1988; Nevitt 1989). However these results were inconclusive since only one site was used and the type of draft diverter was atypical.

The two sites selected for the damper tests are 14 and 20 units respectively, were built in the early 1900's and have single pipe steam heat (6 and 7 in Table 1). As typical in older buildings, there are no dishwashers, but each building has an on-site laundry. The DHW heaters in each building were installed in 1988 and are commercial tank-type units with IFDs, intermittent ignition devices (IID) and rated inputs of roughly 200,000 Btu per hour each. The heaters are controlled by fixed temperature OEM aquastats. Each existing heater was fitted with both a control that allowed the IFD to be enabled or disabled, and a thermal vent damper which could be inserted or removed. This created three test modes (no damper, thermal damper and IFD) which were alternated for one week periods over the course of the one year test period.

Monitoring Protocol and Analytic Methods

Operation of the DHW system in the seven research buildings was monitored with a computerized data acquisition system (DAS). The DAS collected hourly average data, including heater run-time and events, and hot water supply, cold water inlet, boiler room and outside temperatures. For the recirculation control study, return loop temperature was also recorded. Piston-type, positive displacement water flow meters were installed on the cold water inlet lines to measure the volume of water supplied to the water heaters. These meters were equipped with impulse contactor registers that open or close an electrical circuit at intervals proportional to two-and-a-half gallons of water flow. In addition, gas submeters were installed on the DHW heaters at sites 4, 5, 6, and 7, and were read manually on every switch-over day. At sites 1, 2, and 3, the master gas meter for each building was manually read at switch-over.

Hourly data collected by the DAS were reduced to daily averages for each test mode in each building. Average DHW heat input (Btu per hour) for each monitored day was calculated from daily DHW heater run-time data multiplied by a one-time measure of the DHW heater inputs. Each time the DAS measured two-and-a-half gallons of water entering the water heaters, the heat output in Btu was calculated by multiplying the water volume, the average difference in the supply minus inlet water temperatures, the water density (at inlet temperature), and the heat capacity. This calculated heat output was summed over each one-hour period and these values were averaged to obtain the daily average heat output.

Previous research has shown that daily average input and output data from commercial tank heaters fit a linear model (Nevitt and Stefanson 1988). Using this model, a linear regression analysis of daily DHW heat input versus output was performed for each test mode in each building. For the recirculation study, a multiple regression was used, with an added weekday/weekend binary variable. In order to estimate savings, a normalized annual DHW heat output (adjusted for seasonal variations in the inlet water temperatures) was calculated for each building. These normalized outputs were used in the regression models to calculate an annual average DHW input (Btu per hour) for each test mode. Comparisons of these inputs were then used to estimate savings.

Results

Recirculation Control Study

Figure 1 displays the results of the input versus output regression for site 1. Each square represents a daily average input/output from the aquastat mode, whereas the diamonds represent daily averages from the time control mode and the X's represent averages from the demand control mode. In the figure, regression lines are

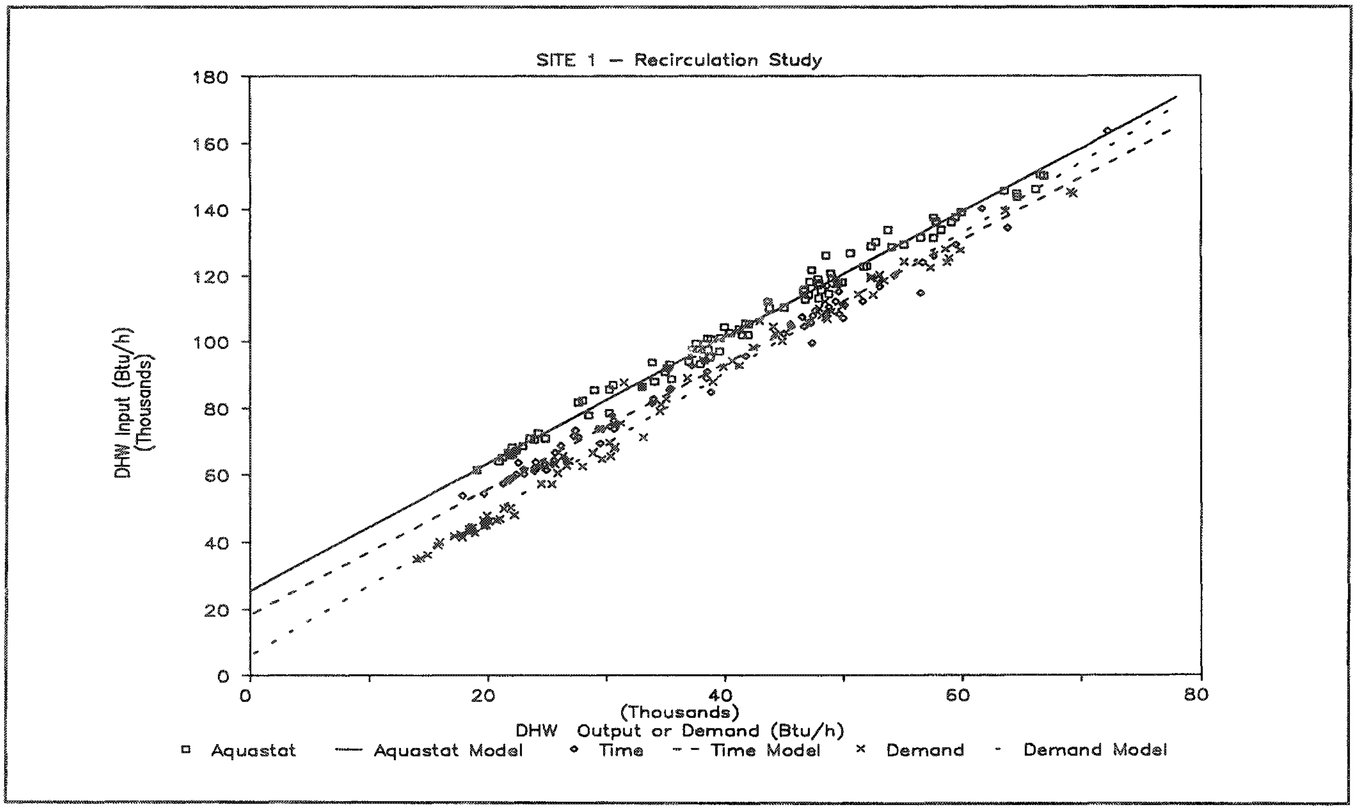

Figure 1. Input Versus Output Regression Model of DHW Use

superimposed on these data points and indicate that for a given output (demand), the time control requires less input than does the aquastat, and the demand control requires less input than either the aquastat or the time control.

Calculated savings for the time control versus the aquastat were 9.8%, 8.1%, and 12.9% with a mean of 10.3% (Table 2). Savings estimates for the demand control over the aquastat were 15.2%, 16.3% and 17.1%, with a mean of 16.2%. Hence, the demand control saved from 3% to 10% more than the time control. All results are highly significant ($P < 0.001$) except for the difference between the time and demand controls at site 2, which is only marginally significant ($0.05 < P < 0.10$). Seasonal efficiencies (including recirculation loop losses) averaged about 35% for the aquastat mode and 38% for the time and demand controls. Efficiencies reported by others for the same type of commercial tank water heaters with recirculation loops are somewhat higher, ranging from 52% to 65% (Perlman and Milligan 1988).

After normalization the annual average outputs for the time and demand controls were lower than the outputs for the aquastats (Table 2), but this was expected, due to reduced demand for fixed-volume uses. These results indicate that a minimum of 10% to 30% of the savings for these controls appears to result from such demand reductions. Therefore, this strategy may also be applicable in buildings without recirculation loops.

Installed cost for the electronic time control were about $1,000 (Table 3), and simple paybacks were 2.3, 3.0, and 1.3 years respectively, with a mean of 2.2 years. By comparison, the demand control cost $1,400 and had simple paybacks of 1.9, 2.2, and 1.6 years, with a mean of 1.9 years. The cost for the demand control was somewhat less in these buildings since three units were installed at one time, but even at a more typical cost of $1,600, the simple paybacks are only increased by two or three months.

Table 2. Results of Recirculation Control Study

	Aquastat	Time	Demand
Site 1			
Annual Output Btu/h:	41136	40064	38210
Annual Input Btu/h:	103543	93397	86680
Annual Efficiency %:	39.7%	42.9%	44.1%
Savings Over Aqua:	n/a	9.8%***	16.3%***
Savings Over Timer:	n/a	n/a	7.2%***
Site 2			
Annual Output Btu/h:	32235	31848	27765
Annual Input Btu/h:	84830	77964	70293
Annual Efficiency %:	38.0%	40.8%	39.5%
% Savings Over Aqua:	n/a	8.1%***	17.1%***
% Savings Over Timer:	n/a	n/a	9.8%***
Site 3			
Annual Output Btu/h:	35005	34276	32682
Annual Input Btu/h:	128560	111971	108974
Annual Efficiency %:	27.2%	30.6%	30.0%
Savings Over Aqua:	n/a	12.9%***	15.2%***
Savings Over Timer:	n/a	n/a	2.7% -
Mean			
Annual Efficiency %:	35.0%	38.1%	37.9%
Savings Over Aqua:	n/a	10.3%	16.2%
Savings Over Timer:	n/a	n/a	6.6%

*** Highly Statistically Significant ($P < 0.001$)

\- Marginally Significant ($0.05 < P < 0.1$)

DHW use profiles generated during the demand control mode seem to indicate that in at least one case the temperature of the DHW heaters could be permanently reduced (e.g., from 140°F to 130°F). One conclusion might be that some of the savings seen in this study could be achieved if building operators reduced system temperatures to the minimum required. While it is reasonable to expect that operators would follow through on such a simple recommendation, our experience indicates that in practice building operators are extremely reluctant to make any changes which might result in tenant complaints. For example, in all three of these test sites the building operators told us that the existing aquastat settings were already at the minimum required to prevent complaints.

Since the issue of tenant satisfaction was important to assess for the controls being tested, caretakers were asked to carefully log any problems during the first two months of operation. No tenant complaints were recorded, although at site 3 the caretaker felt that during the time control mode the hot water temperature was too low for various cleaning duties. As a result, the time control at site 3 was eventually reprogrammed to setback only at night. Tenant surveys were also conducted in all three buildings as well as a control building and no significant pattern of complaints between control modes or buildings could be discerned.

The time controls proved complicated to install and required a second contractor visit to correct miswiring which caused the timers to initially malfunction. By comparison, the demand controls were reasonably straightforward to install. Once in operation, one of each type of control was defective and needed to be replaced. Throughout the test year, the time controls required periodic adjustments to their programs for daylight savings time changes as well as clock inaccuracies. In two instances the timers also lost their programming for no apparent reason. Reprogramming the timers was somewhat difficult to accomplish. In addition, the caretaker at site 3 did not like the idea of time control for DHW and continued to complain about it even after the program was adjusted to setback only at night. By contrast, no problems or complaints were associated with the demand controls throughout the entire test year and no adjustments to the factory program were required. In

Table 3. Costs and Paybacks For Recirculation Controls

	Aquastat	Time	Demand
Site 1			
DHW Cost/Yr*:	$4,535	$4,091	$3,797
Control Cost:	n/a	$1,010	$1,400
Savings/Yr:	n/a	$444	$739
Payback (Yrs):	n/a	2.3	1.9
Site 2			
DHW Cost/Yr*:	$3,716	$3,415	$3,079
Control Cost:	n/a	$900	$1,400
Savings/Yr:	n/a	$301	$637
Payback (Yrs):	n/a	3.0	2.2
Site 3			
DHW Cost/Yr*:	$5,631	$4,904	$4,773
Control Cost:	n/a	$910	$1,400
Savings/Yr:	n/a	$727	$858
Payback (Yrs):	n/a	1.3	1.6
Mean			
Savings/Yr:	n/a	$491	$744
Payback (Yrs):	n/a	2.2	1.9

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* Based on fuel cost of $ 0.50 per 100,000 Btu (one therm)

addition, since program adjustments to the demand control are made with a series of covered, recessed screws (and therefore less obvious), the demand control is probably less likely to be overridden or tampered with by a caretaker.

High Efficiency DHW Heaters

Figure 2 displays the results of the input versus output regression for site 5. Each square represents an average daily input/output from the standard tank heater, whereas the X's represent averages from the high efficiency heater. The regression lines are also displayed in the figure and indicate that the high efficiency heater requires far less input than the standard tank heater to meet the same demand (output).

Annual savings for the installation of the high efficiency heaters are 28.3% and 28.1% (Table 4). These results are both highly significant ($P < 0.001$). Seasonal efficiencies for the existing DHW heaters were 55% for site 4 and 58% for site 5. The energy factor for the tank heater at site 4 was .54, which is quite close to what we measured. No energy factor for the heater at site 5 is available since it has an input greater than 75,000 Btu per hour. Other researchers have reported seasonal efficiencies ranging from 51% to 65% for similar tank-type heaters without recirculation loops (Robinson et al. 1986, 1988; Nevitt and Stefanson 1988; Nevitt 1989). Seasonal efficiencies for the high efficiency heaters tested at sites 4 and 5 were 77% and 81%, which is close to the manufacturer's estimated energy factor of .86.

Installed costs for the high efficiency water heater were $2,800 at site 4 without the secondary storage tank, and $3,500 at site 5 with the secondary tank (Table 5). Paybacks are 24.3 and 27.8 years respectively for the two sites, an insufficient incentive for an owner to replace a working heater. Even if a new heater were required, the added cost of the high efficiency option is estimated at $2,250 for site 4 and $2,550 for site 5, yielding paybacks of 20 years, still higher than most owners are willing to accept without additional motive.

At site 4, the high efficiency heater has been installed for over a year with no difficulties, but at site 5 the unit has had numerous problems. Twice during the first six months of operation, the heater failed to fire and had to be reset per manufacturer's instructions. About six months into the project, the heater developed an irreparable leak

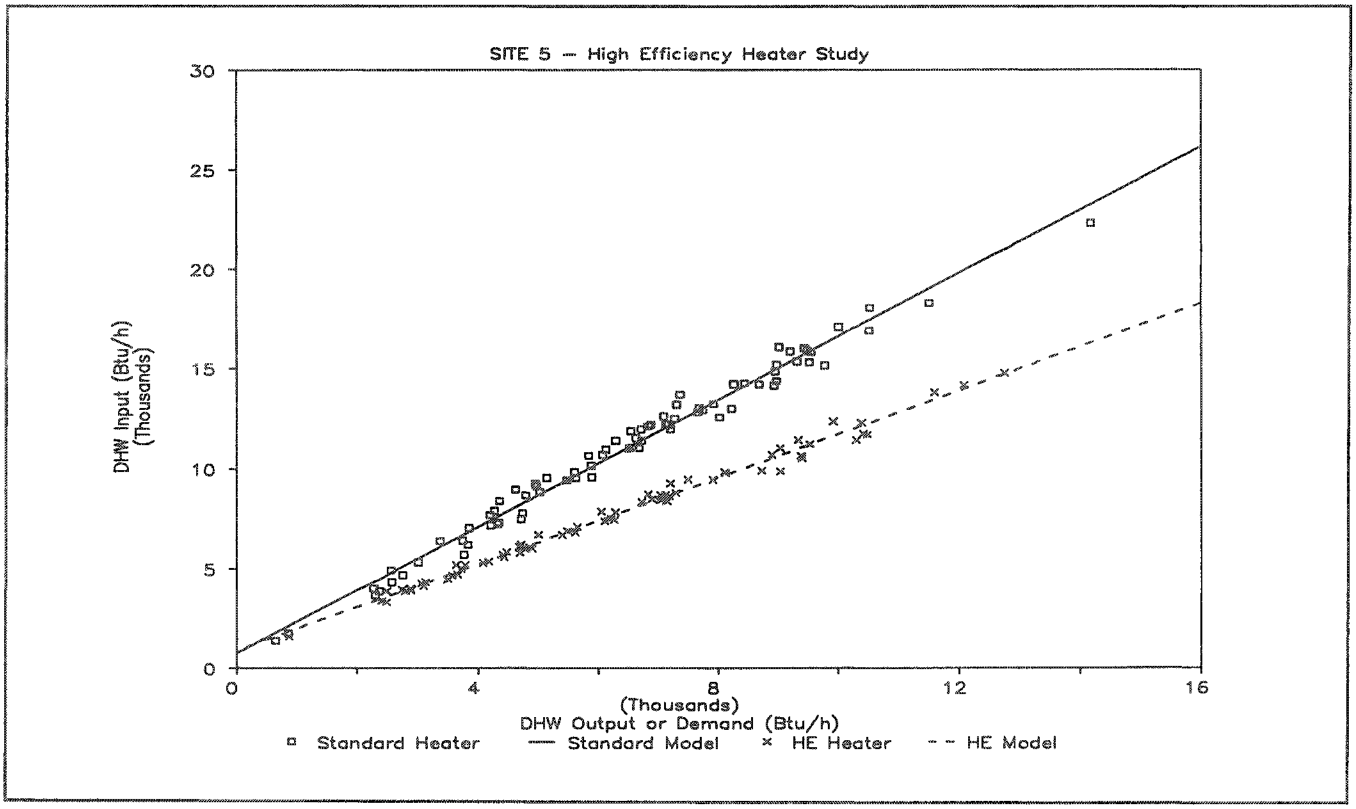

Figure 2. Input Versus Output Regression Model of DHW Use

Table 4. Results of High Efficiency DHW Heater Study

	Standard	HE
Site 4		
Annual Output Btu/h:	5128	5128
Annual Input Btu/h:	9248	6629
Annual Efficiency %:	55.4%	77.4%
% Savings:	n/a	28.3%***
Site 5		
Annual Output Btu/h:	5950	5950
Annual Input Btu/h:	10225	7356
Annual Efficiency %:	58.2%	80.9%
% Savings:	n/a	28.1%***
Mean		
Annual Efficiency %:	56.8%	79.1%
Savings Over Std Htr:	n/a	28.2%

*** Highly Statistically Significant ($P < 0.001$)

Table 5. Costs & Paybacks For High Efficiency Heaters

	Standard	HE
Site 4		
DHW Cost/Yr*:	$405	$290
HE Htr Cost:	n/a	$2,800
Savings/Yr:	n/a	$115
Payback (Yrs):	n/a	24.3
Marginal HE Cost**:	n/a	$2,250
Marginal Payback (Yrs):	n/a	19.5
Site 5		
DHW Cost/Yr*:	$448	$322
HE Htr Cost:	n/a	$3,500
Savings/Yr:	n/a	$126
Payback (Yrs):	n/a	27.8
Marginal HE Cost**:	n/a	$2,550
Marginal Payback (Yrs):	n/a	20.3
Mean		
Savings/Yr:	n/a	$121
Payback (Yrs):	n/a	26.1
Marginal Payback (Yrs):	n/a	19.9

* Based on fuel cost of $ 0.50 per 100,000 Btu (one therm)

** Based on cost differential between HE & Standard heater

and was replaced under warranty. The new heater failed to fire and needed to be reset shortly after installation and about three months later it too developed a leak. The unit was again replaced and has experienced one flame failure since then. The manufacturer has yet to communicate the cause of these failures, although identical problems have been seen with similar equipment made by the same manufacturer (Bohac, et al. 1991). Tenant surveys were not completed at these sites since the replacement equipment was not expected to affect tenant satisfaction, however caretakers were expected to report any complaints. Complaints only occurred at site 5 when the high efficiency heater failed.

IFDs Versus Thermal Flue Dampers

Figure 3 displays the results of the input versus output regression for site 6. While individual data points are difficult to discern because they are so close, the regression lines for the no damper and thermal damper modes are almost coincident, whereas the regression model for the IFD heater is slightly lower.

As might be expected from looking at Figure 1, measured savings from the thermal dampers were insignificant whereas savings from the IFDs, though small, were significant: 6.1% for site 6 and 4.1% for site 7 (Table 6). Seasonal efficiencies for the DHW tank heaters with no vent dampers were virtually identical to the efficiencies with thermal dampers, or roughly 64% and 62%. (It should be noted that these heaters do have IIDs). By comparison, seasonal efficiencies of the heaters with IFDs were 68% and 65%. These results conform well with data from previous DHW damper studies which indicate that thermal dampers on DHW heaters have virtually no significant affect on DHW energy use or efficiency, although they may reduce boiler room infiltration (Stefanson and Nevitt 1988; Nevitt 1989, Sachi, et al. 1989).

Paybacks calculated on the installed cost of DHW heaters with IFDs are 43.3 and 32.0 years respectively for sites 6 and 7 (Table 7). This is much longer than a building owner would typically seek for replacement of an working heater. If the marginal cost of purchasing an IFD heater over a conventional heater is considered at the time of replacement, paybacks are reduced to 9.0 and 12.2 years which is within the 13 year life expectancy for gas heaters of this type, although still longer than most owners will accept.

The IFD water heaters had only one equipment failure. The damper motor at site 7 was replaced under warranty

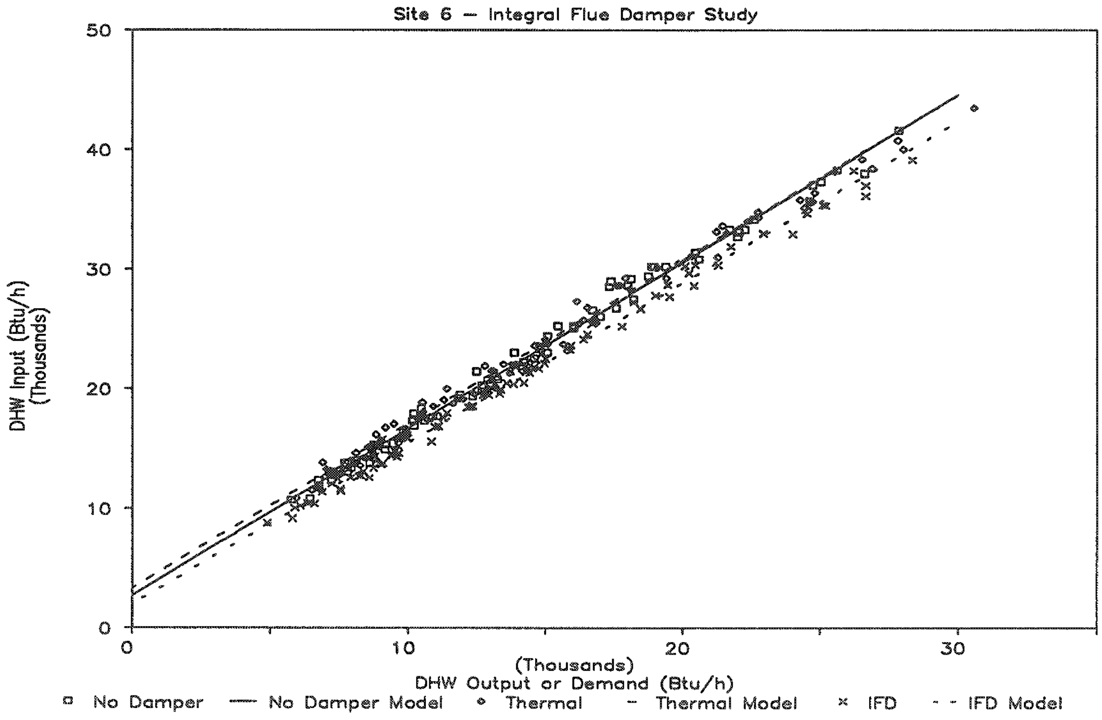

Figure 3. Input Versus Output Regression Model of DHW Use

just prior to the monitoring period encompassed by this study. Tenant surveys were not completed at these sites since the switchovers where not expected to affect tenant satisfaction, and during the test period the caretakers did not report any tenant complaints.

Conclusions

The strategy of lowering DHW tank and recirculation loop temperatures during periods of low demand is worthwhile, even in relatively small multifamily buildings (35 to 50 units). A time-based control which was tested in three buildings had mean savings of about 10% of annual DHW costs, while a demand-based control tested in the same three buildings had mean savings of 16%. Since 10% to 30% of the savings noted in this study appear to be from fixed demand uses, these controls may also be applicable in buildings without recirculation loops. Corresponding paybacks were about 2 years for either control, but given the higher savings potential and ease of operation for the demand control, it is probably the better strategy. Initial malfunctions with each of these controls lead us to recommend that contractors include a monitoring service for a brief period after installation to ensure proper operation.

Based on measured savings in two cases, high efficiency condensing water heaters show potential to reduce DHW energy use by nearly 30% for the multifamily sector. However, currently available water heaters are too small for larger buildings in which the DHW load (and savings potential) can more readily justify the higher cost of this equipment to the building owner. Paybacks found in this study were 20 years or more even when based on the incremental cost of a high efficiency heater over a conventional unit at the time of required replacement. Significant reliability problems were noted with one of the high efficiency heaters used in this study, which is another deterrent for installation of this type of equipment in the multifamily sector, where owners are very sensitive to tenant complaints and maintenance issues.

Commercial tank DHW heaters with IFDs saved about 5% of annual DHW use in two buildings where they were compared to identical heaters without dampers. Paybacks based on the marginal cost of an IFD heater over a conventional heater were about 10 years, but paybacks based on total cost were well over 30 years. Tests of thermal dampers installed on the same heaters showed no efficiency improvement and no savings potential, although this measure may reduce boiler room infiltration.

Table 6. Results of Integral Flue Damper Study

	None	Thermal	Integral
Site 6			
Annual Output Btu/h:	15579	15579	15579
Annual Input Btu/h:	24438	24422	22947
Annual Efficiency %:	63.7%	63.8%	67.9%
Savings Over None:	n/a	0.1% ns	6.1%***
Savings Over Thermal:	n/a	n/a	6.0%***
Site 7			
Annual Output Btu/h:	15197	15197	15197
Annual Input Btu/h:	24357	24245	23357
Annual Efficiency %:	62.4%	62.7%	65.1%
Savings Over None:	n/a	0.5% ns	4.1%**
Savings Over Thermal:	n/a	n/a	3.7%*
Mean			
Annual Efficiency %:	63.1%	63.2%	66.5%
Savings Over None:	n/a	0.3%	5.1%
Savings Over Therm:	n/a	n/a	4.9%

*** Highly Statistically Significant ($P < 0.001$)
** Quite Significant ($0.001 < P < 0.01$)
* Significant ($0.01 < P < 0.02$)
ns Not Significant ($P > 0.5$)

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Table 7. Costs and Paybacks For IFD Heater

	None	Thermal	Integral
Site 6			
DHW Cost/Yr *:	$1,070	$1,070	$1,005
IFD Heater Cost ($):	n/a	$2,595	$2,825
Annual Savings ($):	n/a	$	1$65
Payback (Yrs):	n/a	none	43.3
Marginal IFD Cost ($):	n/a	n/a	$585
Marginal Payback (Yrs):	n/a	n/a	9.0
Site 7			
DHW Cost/Yr *:	$1,067	$1,062	$1,023
IFD Heater Cost ($):	n/a	$900	$1,400
Annual Savings ($):	n/a	$5	$44
Payback (Yrs):	n/a	none	32.0
Marginal IFD Cost ($):	n/a	n/a	$535
Marginal Payback (Yrs):	n/a	n/a	12.2
Mean			
Savings/Yr:	n/a	$	0$55
Payback (Yrs):	n/a	none	37.6
Marginal Payback (Yrs):	n/a	n/a	10.6

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* Based on fuel cost of $ 0.50 per 100,000 Btu (one therm)

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